Knowledge Representation and Ontology for Autonomous Systems

2004 AAAI Spring Symposium

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Brief Problem Statement and Objective

For an autonomous system to behave appropriately in an uncertain environment, many researchers and practitioners feel that "the system must have an internal representation (world model) of what it feels and experiences as it perceives entities, events, and situations in the world. It must have an internal model that captures the richness of what it knows and learns, and a mechanism for computing values and priorities that enables it to decide what it wishes to do." [1]

Autonomous systems in this context refer to embodied intelligent systems that can operate fairly independently from human supervision. A major challenge in autonomous systems is the ability to maintain an accurate internal representation of pertinent information about the environment in which it operates. The inability to do this well hinders effective task planning and execution.

A large body of work exists in various knowledge representation, ontology, and data fusion areas, yet relatively little has been applied to the area of world modeling in autonomous systems. The field of autonomous systems has reached a level of maturity such that it could greatly benefit from leveraging the work that has been on-going in these areas. World modeling in autonomous systems can also serve as a prime problem domain in which to apply theoretical and practical knowledge representation, ontological, and data fusion techniques.

The objective of this symposium is to bring together colleagues in the autonomous systems, knowledge representations, ontology, and data fusion communities to find ways of leveraging existing knowledge technologies to benefit autonomous systems.

Background

There are many types of knowledge that a system must internally model in order to be able to function autonomously. Some of these include:

1) World model data
    - *A priori* knowledge: This is often knowledge that is pre-programmed or referenced for an outside knowledge base. This could include maps of the environment, driving rules of the road, road network information, or characteristics of objects expected to be seen in the environment.
    - *In situ* knowledge: This is knowledge that is learned or acquired in real-time. The source of this knowledge is based upon information perceived from system's sensors, and then processed to infer information. This could include information about instances of objects in the environment and trajectories of moving objects. – a priori and derived from sensor inputs.
2) Value judgments - These are representations of the information that can be inferred about the state of the world relative to the task that is being performed. For example, one may infer that it is unsafe to pass another vehicle on a two-lane undivided highway based upon the existence of a solid double yellow line or a vehicle approaching from the other direction.

3) Gerunds – These are sometimes referred to as 'modes' or 'states'. These are the representations of the present activities that the control system is in the process of doing – the yet-to-be-completed output actions (e.g., a vehicle is "passing" another car, "avoiding" an obstacle or "trying to avoid" an obstacle etc.) These provide a set of real-time self-awareness representations for internal reasoning about what the system itself is trying to do.
4) Representation of the history of task activities – The history of an activity could include sequence and timing information, the state of the world at the time activities occurred, decision and value judgments that were made during the course of the activities, and self-awareness states at each point in the process.
5) Knowledge about the control task – This described how to represent and reason about the internal knowledge for the purpose of control. These could be represented as sets of rules that describe:
    - how the value judgments are to be derived
    - how the value judgments and world model data are to be reasoned about to generate the task outputs
    - how the self-awareness values are to be generated and reasoned about to affect the task outputs
    - how the history is to be represented and reasoned about to affect the task outputs
6) Deep knowledge / Knowledge intent – This focuses on the question of "Why". Why were certain pieces of knowledge captured as opposed to other? Why was this rule created to determine which action an autonomous system should take? Why is this value used to determine a threshold of when an object is safe to traverse over? This, in some ways, can be seen at meta-knowledge, providing additional information about the knowledge that is stored in the world model.
7) Knowledge about the system itself – This would include knowledge about the parts of the system, their capabilities, their constraints, deadlines, their interaction, etc.
8) Task knowledge – This is knowledge about the task that the system is trying to perform. This would include goals to be achieved, priorities, objective measures, constraints, deadlines, etc.

The knowledge in the internal representation must be modeled in such a format that the autonomous system can make maximum use of it. Different types of knowledge inherently require different forms of knowledge representation. At least three different levels of knowledge are required to be represented and reasoned over. They are: [3]

- Parametric knowledge: This could include sensory signals, state variables, and system parameters. This type of knowledge is needed to provide position and/or velocity and/or torque control of each degree of freedom by appropriate voltages sent to a motor or a hydraulic servo valve.
- Spatial knowledge: This is sometimes referred to as "geometric knowledge," "iconic knowledge," "metrical maps," or "patterns." This knowledge is spatial in nature and can be defined as 2D or 3D array data in which the dimensions of the array correspond to dimensions in physical space. The value of each element of the array may be Boolean data or real number data representing a physical property such as light intensity, color, altitude, range, or density. Each element may also contain spatial or temporal gradients of intensity, color, range, or rate of motion. Each element may also contain a pointer to a geometric entity (such as an edge, vertex, surface, or object) to which the pixel belongs. Examples of iconic knowledge include digital terrain maps, sensor images, models of the kinematics of the machines being controlled, and knowledge of the spatial geometry of parts or other objects that are sensed and with which the machine interacts in some way. This is where objects and their relationship in space and time are modeled in such a way as to represent and preserve those spatial and temporal relationships, as in a map, image, or trajectory.
- Symbolic knowledge: In this form of representation, knowledge is represented by the use of symbols. Symbols could represent objects (nouns) or actions (verbs), and their pertinent characteristics and relationships. A large body of relevant work exists in knowledge engineering for domains other than autonomous systems, such as formal logic systems or rule based expert systems. Whether the knowledge is represented in terms of mathematical logic, rules, frames, or semantic nets, there is a formal linguistic structure for defining and manipulating and using the knowledge. Ontologies represent a major body of work that could play a significant role in autonomous systems. [4,5] Potential benefits ontologies can provide include: reuse and

modularity, a centralized approach for representing and reasoning with information about the environment, cheaper and more reliable maintenance, increased flexibility of response for the autonomous vehicle, and it also can extend the range of important questions that can be answered to support navigation planning. [6]

Detailed Objectives

The field of autonomous systems is continuing to gain traction both with researchers and practitioners. Funding for research is this area has continued to grow over the past few years, and recent high profile funding opportunities have started to push theoretical research efforts into practical use. However, much research still needs to be performed in the area of knowledge representation, a vital component of many autonomous systems.

A large body of work exists in efforts to develop knowledge technologies in most, if not all, of the categories of information listed above [2]. However, relatively little work exists on applying these technologies within autonomous systems. Autonomous systems have a need to internally represent information about the environment, and knowledge technologies provide the tools and approach to allow an autonomous system to do so.

This symposium aims to bring together colleagues in the autonomous systems and knowledge technology communities to explore:

- Applying knowledge representations to autonomous systems for representing parametric, spatial, dynamic and symbolic knowledge
- Exploring the usefulness of different types of ontologies for autonomous systems
- Representing *a priori* and *in situ* knowledge, value judgments, state information, history, plans, entities, events, situations, intent, task knowledge, and self-knowledge
- Exploring which knowledge technologies work best for different challenges in autonomous systems, including corresponding performance measures
- Exploring the requirements that subsystems (e.g., sensors, learning modules, planners, and operator control units) place on knowledge representations
- Understanding and formalizing the interaction between disparate knowledge representations (e.g., images, maps, classes, and relationships) that provide complementary information about the same object or event
- Understanding the role of knowledge in model-based perception and control
- Exploring approaches to formalize the autonomous system's internal representation
- Exploring means to measure the quality of knowledge within autonomous systems
- Exploring the reusability of knowledge among disparate autonomous systems
- Determining how data fusion technologies (which support autonomous system sensing capabilities) can be assisted by using knowledge technologies
- Determine mechanisms to ensure a tightly collaboration between colleagues in the autonomous systems and knowledge technology communities

Organizing Committee

Craig Schlenoff (chair), National Institute of Standards and Technology (NIST), USA
Michael Uschold (co-chair), Boeing, USA
Benjamin Kuipers, University of Texas at Austin, USA
James Albus, NIST, USA
Otthein Herzog, University of Bremen, Germany
Charles Shoemaker, US Army Research Lab, USA
Illah Nourbakhsh, Carnegie Mellon University, USA
Hugh Durrant-Whyte, The University of Sydney, Australia
Elena Messina, NIST, USA
James Crawford, NASA Ames Research Center, USA

Michael Gruninger, University of Maryland, College Park, USA
Stephen Balakirsky, NIST, USA

Submission Information

The symposium will consist of formal paper presentations describing current research or visionary approaches, as well as interdisciplinary discussion sessions focusing on topics areas related to knowledge technologies for autonomous systems. Those interested in participating are invited to submit either a full paper (5000 words maximum) or a 1-2 page statement of interest outlining their relevant research activities and how they would like to contribute to the symposium. Please submit papers in PDF format to Craig Schlenoff (craig.schlenoff@nist.gov).

Important Dates

October 3, 2003	**Papers and Statement of Interest Due**
November 7, 2003	**Notification of Acceptance**
January 30, 2004	**Final papers due**
March 22-24, 2004	**AAAI Spring Symposium**

References

1. Albus, J. and Meystel, A., *Engineering of Mind*, John Wiley & Sons, Inc. 2001.

2. Davis, R., "What is in a Knowledge Representation?," *AI Magazine*, 1993.

3. Evans, J., Messina, E., Albus, J., and Schlenoff, C., "Knowledge Engineering for Real Time Control," *Proceedings of the International Workshop on Intelligent Knowledge Management Techniques (I-KOMAT 2002)*, Crema, Italy, 2002.

4. Niles, I. and Pease, A., "Towards a Standard Upper Ontology," *Proceedings of the 2nd Internal Conference On Formal Ontology in Information Systems (FOIS-2001)*, 2001.

5. Schlenoff, C., "Linking Sensed Images to an Ontology of Obstacles to Aid in Autonomous Driving," *Proceedings of the 18th National Conference on Artificial Intelligence: Workshop on Ontologies for the Semantic Web*, 2002.

6. Uschold, M., Provine, R., Smith, S., Schlenoff, C., and Balakirsky, S., "Ontologies for World Modeling in Autonomous Systems," *Submitted to the IJCAI'03 Conference: Workshop on Ontologies and Distributed Systems*, 2003.